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GLAST Shake Test 99 Calorimeter Random Vibration Test Plan

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Abstract

This report presents the test plan and procedure for the GLAST Shake Test 99 Calorimeter random vibration test. A random vibration test is required to ensure the survivability of the calorimeter when subject to the launch environment. The design and workmanship of the calorimeter will be verified and the response data will be used to validate and update the analytical finite element models. GEVS specified random vibration test levels define the launch environment. This test was funded by the Naval Research Laboratory.

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OI	September 20, 1999	E. Swensen, E. Ponslet	Initial release.
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1. Scope

This test procedure describes the random vibration test to be performed on the Shake Test 99 Cesium Iodide (CsI) Calorimeter for the Gamma-ray Large Area Space Telescope (GLAST). The vibration test is to be conducted at the Naval Research Laboratory (NRL) by HYTEC Inc. and NRL personnel. The test is scheduled for September 22nd, 1999 thru September 24th, 1999. This document encompasses all of the pertinent information to set-up and carry out the random vibration test. The following sections will include test objectives, test and instrument set-ups, input levels and an organized test plan and procedures to carry out the vibration tests efficiently.

2. Test Objective

The objective of the random vibration test is to qualify the CsI Calorimeter design to the expected mission environment. The Shake Test 99 calorimeter will be subjected to the vibration levels specified in the General Environmental Verification Specification (GEVS), statistically representative of the mission environment, and the structural response will be measured. The response measurements will be used to qualify the design and calibrate the analytical models used in the design process. The vibration test will provide knowledge of the quality of workmanship, reliability of the design, survivability to the launch environment, interface compatibility with the grid and tracker, and structural response of the CsI logs relative to the calorimeter support structure.

3. Test Article

The Shake Test 99 Calorimeter will be used in the qualification level random vibration testing. The calorimeter closely represents the concept proposed for the flight unit with minor changes, which will be described later.

The concept is described in detail in [2]. It consists of a uni-directional compression cell, holding the CsI logs in position by compressing the stack in the vertical direction between two compression panels. The stack includes several layers of compliant silicon rubber to help control the amount of compression, accommodate tolerances in CsI log dimensions, absorb thermal expansion of the CsI, and provide high friction on the outer surfaces of the logs.

The stack is held in compression by 4 containment panels, bolted to the top and bottom compression panels. Those panels have large rectangular cutouts for clearance to the PIN diodes that instrument the logs, and a number of posts that serve as supports for the PC boards and mechanical connection with the outer shear panels. The containment/shear panel assemblies, tied together with those posts form structural sandwich structures that contain and protect the PC boards, and serve as a backup lateral restraints for the CsI logs.

The Shake Test 99 calorimeter differs from the flight unit conceptual design. Three modifications have been made for the test unit. First, the printed circuit (PC) boards have been left out of most of the testing. It is suspected that the PC boards may strike either the shear panels or the containment panels during the test due to large amplitude response at the corners of the PC boards. The shock response of the PC boards striking the containment panels or shear panels may contaminate the calorimeter data set with misleading response measurements. A final test is planned to replace the PC boards and repeat the transverse random vibration test, once the calorimeter response has been measured.

Second, the bottom compression panel has been manufactured as a solid plate, whereas the flight unit design would use an aluminum honeycomb sandwich construction to minimize weight. All of the assembly features on the solid bottom compression panel have been included to ensure that the shear panels and containment panels are properly fastened and the interfaces identically represent those on the designed flight unit. The solid bottom compression panel is not expected to have any influence on the calorimeter response during the qualification testing.

Finally, the CsI logs have been replaced with aluminum blocks filled with a brass core. The high cost to manufacture the CsI logs prohibits their use during this level of qualification testing. The aluminum replacement logs were sized to match the physical dimensions of the CsI logs and the brass core is used to adjust the weight of the replacement logs so they match the physical weight of the CsI logs during dynamic tests.

The Shake Test 99 calorimeter will be mounted within a test fixture. The test fixture was designed to represent the mechanical interface between both the calorimeter grid (bottom) and tracker subsystem (top). The test fixture has been designed to have a sufficiently large stiffness when compared to the calorimeter so that the measured response of the fixture doesn't couple with the response of the calorimeter at lower frequencies. The exact stiffness will be measured during testing.

4. Test Facility

The vibration tests will be conducted at NRL's, Design, Test and Processing Branch (NRL Code 8210) in the Spacecraft Vibration Test Facility (SVTF). NRL laboratory engineers and technicians will conduct the test and HYTEC Inc. engineers will supervise the test activities. GLAST NRL personnel will be available to assist with test activities and management.

The SVTF has two shakers that will be used during the testing. A horizontal shaker will be used for the transverse axis testing and a vertical shaker will be used for the thrust axis testing. The data acquisition system used in the vibration laboratory is a Hewlett Packard (HP) VXI crates and an HP workstation. The data is post processed in IDEAS and will be converted to MATLAB files for HYTEC analysis.

5. Test Configuration

The Shake Test 99 calorimeter shall be subjected to a random vibration test for two axes, one parallel to the thrust axis (vertical) and the second along the transverse axis (orthogonal to the thrust axis). The second transverse axis will not be subjected to the random vibration test because the calorimeter is symmetrical.

The test configuration will be similar for both test axes. This is intended to reduce the set-up time that will be required to change the test axis. The two changes that will need to be made will be to remove the calorimeter/fixture from the transverse shaker and mount it on the vertical shaker for the thrust test. The accelerometer measurement axis will also need to be changed for some of the uni-axial accelerometers used in the test. The following sections describe the calorimeter test configuration for both the thrust and transverse axes tests.

5.1 Calorimeter Coordinate System

The Shake Test 99 calorimeter was assigned a local coordinate system to orient the calorimeter with the test axes and measured response axes. Several CsI replacement logs have been constructed with a #8-32 female thread to accept accelerometer mounts. Two opposing sides of the calorimeter have 8 logs each with this feature and the two remaining sides have 4 logs each with this feature. The local coordinate system assigned to the calorimeter is oriented such that the two sides with 8 mounting holes define the X-axis. An imaginary line can be drawn from one side to the other, thus defining the axis. The two sides with 4 mounting holes each define the Y-axis, orthogonal to the X-axis. The Z-axis is the third orthogonal axis defined by the right-hand cartesian coordinate system (vertical direction).

Each side of the calorimeter will be assigned a label to distinguish the 6 sides when referenced herein. The coordinate system origin has been assigned to be at the center of the calorimeter. This will allow us to refer to each panel by the normal vector that passes through the face plane, and which side of the origin the panel is located. For example, the +X side, as referred to herein, will be the side with 8 mounting holes on the positive side of the origin (the positive side will be indicated on the test fixture). The –X side will be the side with 8 mounting holes on the negative side of the origin. This is true for the Y axis as well. The top compression panel will be the +Z side and the bottom compression panel will be the –Z side. The calorimeter will be subjected to vibrations along the X-axis for the transverse tests and the Z-axis for the thrust tests.

5.2 Calorimeter/Test Fixture Set-up

The calorimeter will be mounted in a test fixture assembly designed to replicate the mounting configuration of the flight unit. Four mounting surfaces are provided at the top and bottom of the fixture to represent the mounting interface to both the tracker (top) and the grid (bottom). The test fixture has been designed with very high stiffness to reduce the response of calorimeter/test fixture coupled modes.

The calorimeter assembly was mounted in the test fixture at HYTEC Inc. prior to shipping to NRL. The calorimeter was placed on the fixture base plate separated by the four lower spacers. It was secured to the fixture base plate using four ½" x 5/8" long shoulder bolts and torqued to 20 ft-lbs. The threads were coated with medium strength Locktite™ to keep them from coming loose during testing. The medium strength Locktite™ is not a permanent bond. The bond can be separated if the bolt needs to be removed during or after the testing is complete.

The top plate was lowered onto the calorimeter, separated by the four upper spacers. The top plate was aligned with the four mounting locations and secured with four 5/16" x 5/8" long shoulder bolts and torqued to 64 in-lbs. The threads were also coated with medium strength Locktite™ to keep them from coming loose during testing.

The two shear plates (small) were positioned on the +Y and –Y sides. The fasteners were engaged (finger tight) in the top and bottom fixture plates, but were not tightened at this time. The two long shear plates were positioned on the +X and –X sides. The 3/8-16 and ¼-20 fasteners were engaged (finger tight) to align the six fixture plates. The four shear plates were tightened at this time to an unspecified torque level to align the side plates with the top and bottom plates. The two long shear plates were removed so that the calorimeter could be prepared for the shipment to NRL.

Strain gage sensors were used during the calorimeter/test fixture assembly to ensure that undue strains were not being introduced into the calorimeter during the assembly process.

5.3 Test Fixture/Shaker Table Mounting

The test fixture will be mounted to each shaker using 56, 3/8" x 1.5", fasteners. The mounting configuration is identical for both the horizontal and vertical shakers. The fasteners clearance holes are located on the fixture base plate, inside the test fixture. Access to the fastener locations can be obtained by removing the two long shear plates from the fixture. All 56 holes should be accessible from these two sides, however there may be a need to remove the two additional shear plates if the clearance between the shear plates and calorimeter is not sufficient or access to the ±Y sides is required. Avoid striking the calorimeter while securing the bolts. Torque all 56 fasteners to 350 in-lbs to ensure proper pressure is maintained during testing.

5.4 Accelerometer Set-up

5.4.1 Accelerometer Mounting Configuration Description

The accelerometers are to be mounted on the shaker table, test fixture and calorimeter during both the transverse and thrust axis testing. Thirty nine accelerometer locations have been defined to make referencing easier, however not all of the defined locations will be instrumented with accelerometers during testing. Predefined locations have been reserved if it becomes necessary to later instrument a particular location with an accelerometer. The thirty nine accelerometer designations are identified in section 14.1 and 14.2 of Appendix B, for both the transverse and thrust axis tests, respectively. The missing information is to be recorded at the time of the test. Additional accelerometer locations defined at the time of testing preparation can be recorded at the bottom of table 14.1 or 14.2, when applicable.

5.4.1.1 Shaker Table

The shaker table is to be instrumented with a minimum of one accelerometer to measure the input excitation of the test being conducted. The accelerometer may be mounted either on the shaker table, near the test fixture, or on the test fixture near the table. If the accelerometer is place on the test fixture, ensure that the accelerometer is placed in a position that will measure the input excitation without amplification of the measurement signal that will occur at resonance. This requires the accelerometer to be placed on a very stiff structural component or at a known modal node for all the frequencies within the random vibration bandwidth. The input measurement accelerometer will be assigned channel 1 in the data acquisition system.

5.4.1.2 Calorimeter

The calorimeter has been assigned twenty three independent channels. The first 8 locations, 2 through 9, are reserved for uni-axial miniature accelerometers mounted on the CsI replacement logs on the +X side. Each mounting hole has been assigned a number reading from left to right and top to bottom. There are four rows of logs and each has two channels associated with it. The channels are numbered consecutively with 2 being the 1st row (top) left, 3 is the 1st row right, 4 is the 2nd row left, 5 is the 2nd row right, 6 is the 3rd row left, 7 is the 3rd row right, 8 is the 4th row (bottom) left, and 9 is the 4th row left. The +Y side CsI replacement logs will use four uni-axial miniature accelerometers, sequenced similarly with 10 at the upper left, 11 at the upper right, 12 at the bottom left, and 13 at the bottom right. The –X and –Y sides have mounting locations available, but are not being given an independent channel. If used, the channel designation will be the same as the one on the opposite side of the CsI replacement log.

Two channels have been reserved for the top compression panel. Channel 14 will be reserved for the +X edge (at the center) and channel 15 will be reserved for the +Y edge. There is only enough clearance to accommodate uni-axial miniature accelerometers at these locations.

Each shear panel will have one location assigned with the exception of the +X shear panel. The +X shear panel will have three channels to capture its mode shape. Channel 16 will be at the top, 17 at the middle, and 18 at the bottom. Channel 19, 20, and 21 will be located at the center of the shear panel on the +Y, –X, and –Y sides, respectively. Tri-axial accelerometers should be used on the shear panels to capture the full response and reduce the set-up time.

5.4.1.3 Test Fixture

The test fixture has been assigned fifteen locations. Most will not be used, but are available if needed. Seven locations each have been assigned to the long shear plate on the +X side and on the shear plate on the +Y side. One location has been reserved for the top plate, center. The numbering sequence used to identify all of the fixture locations is such that the first locations listed are those that are intended to be used. The remaining locations are reserved if needed. Table 14.1 and 14.2 list the accelerometer locations and are to be used to record the accelerometer location information.

5.4.2 Accelerometer Locations used for the Vibration Testing

5.4.2.1 Shaker Table

The shaker table will be instrumented with one or more accelerometers as indicated in section 5.4.1.1.

5.4.2.2 Calorimeter

5.4.2.2.1 Transverse Axis Testing

The calorimeter will be instrumented with accelerometers on the +X side, +Y side and top compression panel. The accelerometer mounts will be used to mount the uni-axial miniature accelerometers to the CsI replacement logs at the locations indicated in section 14.1. All eight channels on the +X side and two of the four channels, 11 and 12, on the +Y side will be used to measure the response of the CsI logs in the X direction. The two remaining channels on the +Y side will be used to measure the response of the CsI logs in the Y direction.

The top compression panel will be instrumented with one uni-axial miniature accelerometer mounted at the center of the +X edge. Place the accelerometer away from the edge at a distance of about ¼ of the panel width, if possible.

The shear panels will be instrumented with miniature accelerometers at the 6 locations, 16 through 21, indicated in section 14.1. The +X and –X sides will have uni-axial accelerometers to measure the response in the X direction. The +Y and –Y sides will have tri-axial accelerometers to measure all three directions simultaneously without having to change the measurement between tests.

Use an appropriate adhesive to secure the accelerometers to the test article where mounting holes are not provided.

5.4.2.2.2 Thrust Axis Testing

The calorimeter will be instrumented with accelerometers on the +X side, +Y side and top compression panel. Accelerometer mount #1 will be used to mount the uni-axial miniature accelerometers to the CsI replacement logs at the locations indicated in section 14.2. These mounting locations are identical to those specified for the transverse axis test, but must be oriented so that they measure the response in the vertical direction. Accelerometer mount #1 has four surfaces to place accelerometers. Orient the mount so that there is a mounting surface parallel to the horizontal plane, and mount the accelerometers on this surface using an appropriate adhesive.

The top compression panel will be instrumented with one uni-axial miniature accelerometer along the +X edge near the center. The accelerometer should have been mounted to the calorimeter during the transverse tests, but if not place the accelerometer away from the edge at a distance of about ¼ of the panel width.

The shear panels will be instrumented during the transverse tests and should not be changed. If the thrust test is being performed first, review section 5.4.2.1 for the appropriate mounting locations.

Use an appropriate adhesive to secure the accelerometers to the test article where mounting holes are not provided.

5.4.2.3 Test Fixture

The test fixture will be instrumented with accelerometers on the +X side, +Y side, and the top plate. Five channels will be used on the +X side, 25, 26, 27, 30 & 32, mounted in locations specified in Appendix B.

Two channels will be instrumented on the +Y side, 35 and 38, and one channel on the top plate, channel 29. Mounting holes are provided at the top and bottom of the panel, but the center accelerometer will need to be mounted using an appropriate adhesive.

5.5 Strain Gage Sensor Set-up

The calorimeter has been instrumented with strain gage sensors to measure the static relaxation of the calorimeter after the initial compression. The sensors are available, therefore they will be used during the dynamic tests to measure the strain in real time.

The calorimeter was instrumented with 20 strain gage sensors on the containment panels, compression panels and shear panels. Each containment panel has been instrumented with three strain gage sensors at its mid-plane, one at the left edge, one at the center and one at the right edge. Each sensor is a single axis gage oriented to measure the strain along the Z-axis.

The top and bottom compression panels have been instrumented with two strain gage sensors each at the center of the panel. They are single axis gages oriented to measure the strain along both the X-axis and the Y-axis.

The shear panels have been instrumented with strain rosettes to measure the shear in the panels. Each shear panel has one rosette at the center of the panel that is oriented to measure the strain along the Z-axis and ±45° off the Z-axis. The +X side strain gage sensors will not be used during the testing, but the +Y side strain response will be monitored during both tests.

6. Sine Sweep Test Levels

The low amplitude sine sweep test is used to estimate the transfer function of the calorimeter parallel to both the thrust and transverse axes. The sine sweep is not designed to measure the structural response when subjected to the launch environment, but is intended to identify the resonance frequencies and the modal loss factor of the calorimeter. The estimated transfer function obtained from the sine sweep test will be used to help detect structural damage that may occur during the sine burst and random vibration tests. The resonant frequency and modal loss factor information will allow the test levels to be adjusted during testing, if necessary. This information will also identify the appropriate channels to be used as controller feedback to limit the input during random vibration testing with notch-filtering.

The acceleration level used for the sine sweep test is calculated using the following formula:

$$a = [A\,(2\cdot\pi\cdot f)^2] / 9.81 \tag{6.1}$$

where,

$$A = 2\cdot Q\cdot u_{base}$$

Here,

a = base acceleration in g's,
A = amplitude of structural response in meters,
Q = quality factor of the mode,
u_{base} = base displacement in meters,
f = fundamental frequency of the calorimeter in Hz.

The response amplitude, A, is defined as the maximum amplitude of a sinusoidal function, where $\sin(\omega) = 1$, for a given acceleration at a given frequency. A finite element analysis (FEA) identified the calorimeter fundamental frequency to be 59 Hz. The mode shape was identified to have a sinusoidal deflection with the maximum deflection at the center row of CsI replacement logs. The quality factor, Q, was estimated to be 10. The FEA solution was used to calculate the sine sweep acceleration levels.

The sine sweep test is intended to estimate the transfer function and not measure the response, therefore two acceleration levels have been defined for the sine sweep test. The target level will be used as the initial, or starting, acceleration. The maximum acceleration level will define the upper limit of acceleration if the target level is too low and must be increased. The target level can be increased during testing until the maximum acceleration is reached. If the target acceleration must be increased above the maximum level, the calorimeter response must be thoroughly understood to avoid striking the shear panels with the CsI replacement logs.

The target value was calculated by estimating the minimum response of the calorimeter and comparing it to an expected signal-to-noise ratio. A target deflection of $36\mu m_{0\text{-}pk}$ was selected, which equates to an acceleration level of 0.5 $g_{0\text{-}pk}$. The target value may need to be reevaluated after the initial tests if the analytical fundamental frequency is incorrect or the noise is too high to identify the transfer function with a high degree of confidence.

The maximum acceleration is defined by the maximum desired response of the calorimeter at the center logs. The calorimeter has been designed with a 1 mm clearance between the CsI replacement logs and the containment panels. A layer of compliant foam couples the containment panel with the logs. The foam layer will compress during testing, transferring the forces from the CsI logs into the containment panels. To avoid damage to the containment panels, the maximum foam layer compression has been arbitrarily selected to allow the foam to compress to 15% of its thickness. The containment panels and CsI logs have different fundamental frequencies, therefore the maximum deflection is limited to 150 $\mu m_{0\text{-}pk}$. The maximum acceleration level is calculated to be 2.1 $g_{0\text{-}pk}$.

The sine sweep will be swept over the frequency range from 10 Hz to 2000 Hz. The random vibration test will be performed over the frequency range from 20 Hz to 2000 Hz. 10 Hz was selected to ensure that the lower frequency modes are captured, should they exist. The sweep rate has been selected to be 4 $^{oct}/_{min}$. This value was selected to avoid transient response of the calorimeter as the sweep passes through resonance. Table 6.1 summarizes the sine sweep acceleration levels.

Table 6.1. Sine Sweep Acceleration Levels.

	Level	Frequency	Duration	Max Response
Target	0.5 $g_{0\text{-}pk}$	10-2000 Hz	4 $^{Oct}/_{min}$	36 $\mu m_{0\text{-}pk}$
Maximum	2.1 $g_{0\text{-}pk}$	10-2000 Hz	4 $^{Oct}/_{min}$	150 $\mu m_{0\text{-}pk}$

The sine sweep levels were calculated using the worst-case calorimeter response. The worst case response is in the transverse direction. The thrust axis response is not expected to be as severe, therefore both tests will use the levels defined in Table 6.1.

7. Sine Burst Test Levels

The Shake Test 99 calorimeter will be subjected to a qualification level sine burst test to validate the design concept to the launch environment and qualify the workmanship. The sine burst test is designed to subject the calorimeter to the quasi-static limit load factors used in the design analysis. The limit load factors are defined in the GLAST Science Instrument – Spacecraft Interface Requirements Document (SI-SC IRD), paragraph 3.2.2.7.2.

The acceleration levels used for the qualification level sine burst test are defined by adding 25% to the limit load factors defined in the SI-SC IRD. The limit loads are given to be ±4.0 g's$_{0\text{-}pk}$ in the lateral direction during liftoff and transonic events, and ±6.6 g's$_{0\text{-}pk}$ during the main engine cutoff. The acceleration levels for the qualification level sine burst test are calculated to be ±5.0 g's$_{0\text{-}pk}$ in the transverse direction and ±8.25 g's$_{0\text{-}pk}$ in the thrust direction.

The acceleration levels have been defined, but an acceptable frequency must be calculated. Because this is a quasi-static test, the frequency used for the sine burst test must be low enough to avoid exciting the resonance of the structure. This will cause large deflections and possible damage to the calorimeter. The deflection amplitude will dictate the sine dwell frequency, therefore the largest obtainable amplitude will be used to define the dwell frequency. The vertical and horizontal shakers are believed to have a maximum range of 1" (0.025 m) pk-pk. This amplitude will be used to calculate the excitation frequency. The sine burst dwell frequency is calculated using the following equation:

$$a = [A\,(2\cdot\pi\cdot f)^2] \,/\, 9.81 \tag{7.1}$$

Here,

a = base acceleration in g's,
A = amplitude of base excitation in meters,
f = dwell frequency in Hz.

Using the base acceleration levels and excitation amplitude outlined in the previous paragraph, the dwell frequency can be backed out of equation 7.1. The dwell frequency for the transverse axis test was calculated to be 9.9 Hz. The dwell frequency for the thrust axis test was calculated to be 12.7 Hz. Table 7.1 summarizes the sine burst test levels.

Table 7.1. Sine Burst Test Levels

Test Axis	Dwell Frequency	Acceleration Level	Duration
Transverse	9.9 Hz	±5.0 g's$_{0\text{-pk}}$	5 cycles
Thrust	12.7 Hz	±8.25 g's$_{0\text{-pk}}$	5 cycles

8. GEVS Specified Random Vibration Test Levels

The Shake Test 99 calorimeter random vibration test levels are specified in the GEVS, section 2.4 – "Structural and Mechanical", paragraph 2.4.2.5 – "Component/Unit Vibroacoustic Tests", sub-paragraph (a) – "Random Vibration." This paragraph outlines that the test component (calorimeter) shall be subjected to a random vibration along each of three mutually perpendicular axes for one minute each. When possible, the random vibration spectrum shall be based on levels measured at the mounting locations during previous testing. The second alternative is to use a statistically estimated response of similar components mounted on similar structures or on analysis of the payload. The Generalized Vibration Test Specification of Table 2.4-4 is used when previous measurements of similar structures and analytical solutions are not available.

GEVS Table 2.4-4 is used to determine the test levels for the Shake Test 99 calorimeter testing because response data from like structures and analyses are not available. The table gives exact qualification and acceptance level Acceleration Spectral Density (ASD) functions, given in $^{g^2}/_{Hz}$, for components weighing 22.7 kg. Qualification levels are defined as the flight limit level, acceptance, plus 3 dB. The table also specifies that the ASD levels may be reduced for components weighing more than 22.7 kg, and must adhere to the following equations for qualification levels:

DB Reduction = 10 log(W_1 / 22.7) 10 log(W_2 / 50) (8.1)
ASD(50-800 Hz) = 0.16 (22.7 / W_1) 0.16 (50 / W_2) (8.2)

Where, W_1 = Component Weight in kg.
W_2 = Component Weight in Lbs.

The minimum ASD level must be maintained at 0.01 $^{g^2}/_{Hz}$ at 20 and 2000 Hz for components that weight more than 59 kg and the slope from 20 to 50 Hz and 800 to 2000 Hz, shall be adjusted to maintain these levels.

The actual Acceleration Spectral Density levels that are to be used in the random vibration test of the Shake Test 99 calorimeter are listed in Table 7.1. Figure 7.1 illustrates the ASD levels for the vibration tests and indicates the maximum and minimum values outlined in the GEVS. The actual ASD levels used for the random vibration test were calculated using the actual Shake Test 99 calorimeter weight of 111.4 kg (245 lbs). This weight was measure prior to installation inside the test fixture.

Table 7.1. Acceleration Spectral Density Levels for the Random Vibration Test.

Frequency (Hz)	ASD Level ($^{g^2}/_{Hz}$)
20	0.01
20 to 50	+3.92 $^{dB}/_{oct}$
50 to 800	0.033
800 to 2000	-3.92 $^{dB}/_{oct}$
2000	0.01
6.81 grms	

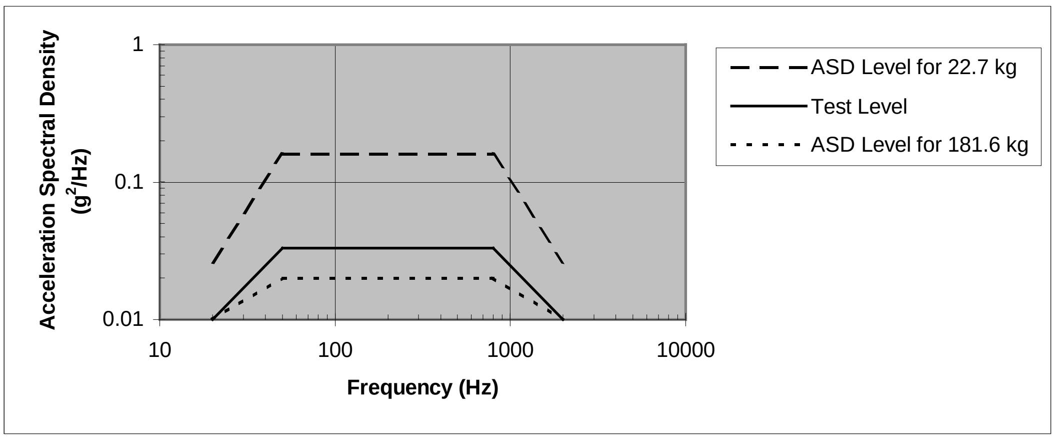

Figure 7.1. Generalized Random Vibration Test Levels for the Shake Test 99 Calorimeter.

The GEVS also allows these levels to be notched around fundamental modes of delicate equipment such as the CsI calorimeter when damage to the hardware is likely to occur. Both tests will be stepped up to avoid damage to the calorimeter. Each axis will be subjected to a random vibration at –6 dB * 6.81 g_{rms}, at 6.81 g_{rms} with notch filtering, and finally at 6.81 g_{rms} without notch filtering. This will allow the calorimeter performance to be monitored at various levels of random vibrations.

9. Instrumentation

9.1 Accelerometers

Specific instrumentation is not outlined in this section. The accelerometers used for the random vibration test acceleration measurements should be readily available at the NRL vibration facility and should not require any special needs. The accelerometers should be sensitive enough to measure the acceleration levels outline in sections 6 – 8.

9.2 Strain Gage Sensors

Strain gage sensors have been mounted on the Shake Test 99 calorimeter prior to shipment to NRL. These gages are sensitive and must be handled with some caution to avoid damage prior to testing.

10. Generalized Test Plan

An organized test plan has been put together to ensure that the maximum amount of valuable information can be obtained in the unlikely event a mechanical failure of the Shake Test 99 calorimeter should occur before the testing has been completed. Four tests will be performed in two of the three orthogonal directions, parallel to one of the transverse axes and parallel to the thrust axis. The tests will include a low amplitude Sine Sweep test, a full amplitude Sine Burst test, a full amplitude random vibration test with notch-filtering at the structural resonance's, and a full amplitude random vibration test without notch-filtering at the structural resonance's. Here, notch-filtering is defined as controlling or limiting the maximum response of a selected control accelerometer so that structural amplification around resonance does not exceed qualification levels defined in the GEVS. One or more channels can be limited if the response is expected to exceed GEVS levels, resulting in possible damage to the calorimeter. However, because this is mechanical prototype, the calorimeter will also be subjected to the GEVS level random vibrations without notch-filtering to better understand the calorimeter dynamics and limitations. Each of the four test described will be performed both parallel to the transverse (horizontal) axis and parallel to the thrust (vertical) axis. Symmetry of the calorimeter eliminates the need for an additional test parallel to the second transverse axis.

Time is limited during testing, therefore, the tests will be arranged such that the number of set-up's are minimized. The optimum test plan solution is to set-up the transverse axis tests and subject the calorimeter to all of the vibration tests before breakdown. The thrust axis test will then be set-up and the calorimeter will be subjected to all of the vibration tests before completing the testing. This will reduce the number of test set-ups to two.

The tests will be organized as outlined in Appendix A. Section 13.1 summarizes the test plan for the transverse axis. Section 13.2 summarizes the test plan for the thrust axis. The test procedure will be performed in the same sequence for both axes, with the exception of one additional test along the transverse axis.

Each test axis will begin with a shaker evaluation to ensure the controller is functioning properly and the test levels have been programmed correctly. An instrumentation check will follow using a 0.25 $g_{0\text{-}pk}$ once the calorimeter has been assembled on the respective shaker table to verify instrumentation operation.

Calorimeter testing will begin with a sine sweep, at levels outline in Section 6, to define the sine sweep test levels and obtain a baseline estimate of the calorimeter transfer function. Each test will be followed by a diagnostic sine sweep to compare the transfer functions before and after each test. It is possible to replace the sine sweep evaluation with an equivalent low-level random vibration evaluation to estimate the calorimeter transfer function. An equivalent low-level random vibration would be on the order of < 1 g's.

The sine burst and random vibration test levels will be stepped up in two increments. The low amplitude sine burst test will be conducted first at ½ the acceleration levels defined in Section 7, followed by the random vibration test at –6 dB of the maximum amplitude defined in Section 8. Again, each test will be followed by a diagnostic sine sweep.

The full amplitude sine burst test will be conducted next at the levels outlined in Section 7.

The full amplitude random vibration tests will be conducted next with notch-filtering at the levels outlined in Section 8. Locations 4 and 7 may be used as the control channels to limit the response of the CsI replacement logs around resonance's. A final full amplitude random vibration test without notch-filtering will complete the thrust axis testing.

The transverse axis will be subjected to one additional test, prior to switching to the vertical shaker. One PC board will be mounted on the +X side between the calorimeter containment panels and the shear panels. It will be instrumented with 2 or three accelerometers, and the response of the PC board will be measured when the calorimeter is subjected to the full amplitude random vibration test without notch-filtering.

The data will be delivered to HYTEC engineers for evaluation and a report will be written to summarize the test results.

11. Test Procedures

The following paragraphs outline the test sequence to set-up and perform all of the vibration tests on the *Shake Test 99 calorimeter*.

11.1 Calorimeter/Fixture Set-Up

11.1.1 Unpacking the Calorimeter/Test Fixture

If not previously done, begin by unpacking the *Shake Test 99 calorimeter* from the shipping crate. The top and one side must be removed to gain access to the calorimeter. Remove the side of the crate that will allow access to the *long shear plate* (P/N GLS-BTC5-5007) of the test fixture. Remove the protective plastic to expose the calorimeter. Remove the exposed *long shear plate* from the test fixture to gain access to the inside of the test fixture. The calorimeter has been fastened to the crate using 7 fasteners, 5 3/8" lag screws and 2 3/8" bolts. All seven fasteners must be removed before separating the calorimeter from the shipping crate. Lift the test fixture with calorimeter from the shipping crate using two straps routed through the two view ports on each side of the fixture. Use a forklift, hoist or similar lifting device capable of lifting 500 lbs to move the calorimeter.

11.1.2 Perform Shaker Operation Evaluation Tests

Before mounting the calorimeter on either the vertical or horizontal shaker, the shaker operation must be evaluated. Begin by programming the controller with the test levels outlined in sections 6, 7 and 8. Perform a wedge check of 5gpk at 20 Hz (0.25" pk-pk) to verify shaker operation. Continue by verifying that the sine burst levels and random vibration levels have been programmed correctly.

11.1.3 Mounting the Calorimeter to the Shaker

Place the calorimeter on the horizontal or vertical shaker (when applicable) in the appropriate position on the shaker table. Remove the second *long shear plate*, and the two *shear plates* (P/N GLS-BTC5-5003) from the test fixture to gain access to all of the *base plate* (P/N GLS-BTC5-5002) fastener locations. Engage all 56, 3/8-16 x 1.5", fasteners (finger tight) to the table. Secure the calorimeter test fixture by tightening the bolts to 350 in-lbs.

11.1.4 Calorimeter Instrumentation Set-Up – Internal to the Shear Panels

Unpack the strain gage sensor cables from their respective plastic bags and discard the bags and tape. Carefully straighten each strain gage sensor cable and lay flat on the shaker table. Be sure to avoid inducing extraneous stress into the strain gage solder connections; they are fragile connections and may come undone. Route the strain gage sensor cables through one of the *shear plate* view ports (if strain gage information is desired). If the strain gage sensor are not going to be used, secure them to the base plate so they don't move around during testing.

Fasten *accelerometer mount #1* (P/N GLS-BTC5-5005) to the calorimeter *CsI replacement logs* (P/N GLS-BTC5-3001) for the thrust axis tests. Fasten *accelerometer mount #2* (P/N GLS-BTC5-5006) to the calorimeter *CsI replacement logs* for the transverse axis tests. The accelerometer mount locations are listed in table 11.1.4.1, and are to be used for the transverse configuration. Table 11.1.4.2 gives accelerometer mount locations for the thrust configuration. Torque each mount or screw to 28 in-lbs. The accelerometer mount locations match the accelerometer locations identified in Appendix B for the *CsI replacement logs*.

Table 11.1.4.1. Mounting Locations for the Accelerometer Mounts used on the Transverse Axis Testing.

No.	Location	Measurement Axis
Accelerometer Mount #1 (P/N GLS-BTC5-5005)		
11	CsI replacement logs, +Y Side, 1st Row Right	+X
12	CsI replacement logs, +Y Side, 2nd Row Left	+X
Accelerometer Mount #2 (P/N GLS-BTC5-5006)		
2	CsI replacement logs, +X Side, 1st Row Left	+X
3	CsI replacement logs, +X Side, 1st Row Right	+X
4	CsI replacement logs, +X Side, 2nd Row Left	+X
5	CsI replacement logs, +X Side, 2nd Row Right	+X
6	CsI replacement logs, +X Side, 3rd Row Left	+X
7	CsI replacement logs, +X Side, 3rd Row Right	+X
8	CsI replacement logs, +X Side, 4th Row Left	+X
9	CsI replacement logs, +X Side, 4th Row Right	+X
10	CsI replacement logs, +Y Side, 1st Row Left	+Y
13	CsI replacement logs, +Y Side, 2nd Row Right	+Y

Table 11.1.4.2. Mounting Locations for the Accelerometer Mounts used on the Transverse Axis Testing.

No.	Location	Measurement Axis
Accelerometer Mount #1 (P/N GLS-BTC5-5005)		
2	CsI replacement logs, +X Side, 1st Row Left	+Z

3	CsI replacement logs, +X Side, 1st Row Right	+Z
4	CsI replacement logs, +X Side, 2nd Row Left	+Z
5	CsI replacement logs, +X Side, 2nd Row Right	+Z
6	CsI replacement logs, +X Side, 3rd Row Left	+Z
7	CsI replacement logs, +X Side, 3rd Row Right	+Z
8	CsI replacement logs, +X Side, 4th Row Left	+Z
9	CsI replacement logs, +X Side, 4th Row Right	+Z
11	CsI replacement logs, +Y Side, 1st Row Right	+X
12	CsI replacement logs, +Y Side, 2nd Row Left	+X
Accelerometer Mount #2 (P/N GLS-BTC5-5006)		
10	CsI replacement logs, +Y Side, 1st Row Left	+Y
13	CsI replacement logs, +Y Side, 2nd Row Right	+Y

Mount one *ENDEVCO Model 2222C* miniature piezoelectric accelerometer to each accelerometer mount using an appropriate adhesive. The transverse axis tests will require the accelerometer to be mounted to measure the response in the transverse direction. The thrust axis tests will require the accelerometer to be mounted to measure the response in the thrust direction for each accelerometer. Route the accelerometer cables through the second view port (not used for strain gage sensors) of the *shear plate*.

The *shear panels* (P/N GLS-BTC5-1002) may be instrumented with miniature accelerometers. It is not part of this test plan but may provide some valuable response characteristics of the calorimeter. If the *shear panels* are instrumented with accelerometers, be sure to record their location and other vital information in the table in section 14.1 or 14.2 (where applicable).

11.1.5 Calorimeter Final Assembly

Enclose the *Shake Test 99 calorimeter* by replacing the calorimeter *shear panels* on all four sides. Check for alignment with the *top* and *bottom compression panels* (Top – P/N GLS-BTC5-1007 and Bottom – P/N GLS-BTC5-1006) and with the *spacer spools* (Inner – P/N GLS-BTC5-1005 and Outer – P/N GLS-BTC5-1004) on the *containment panels* (P/N GLS-BTC5-1001). Insert a few screws in the *top* and *bottom compression panels* (finger tight) to hold it in place. Be sure to route the accelerometer and strain gage sensor cables out the bottom of the calorimeter, between the *containment panel* and the *shear panel*. More importantly, be sure the cables are not pinched between the *bottom compression panel* (P/N GLS-BTC5-1006) and the *shear panel*.

Engage the remaining screws (finger tight) with the *top* and *bottom compression panels* as well as with the *connection posts* on the *containment panel*. Repeat these steps for each of the three remaining panels. Torque all of the #3 screws to 4 in-lbs and all of the #4 screws to 6 in-lbs.

11.1.6 Calorimeter Instrumentation Set-Up – Exterior

Mount one miniature piezoelectric accelerometer to the *top compression panel* at the center of the +X edge at a distance of ~¼ w, where w is the calorimeter width, towards the center of the panel.

Mount three accelerometers on the +X *shear panel*. Mount them vertically with one at the top center, a second at the panel center and the third at the bottom center. These locations are also listed in Appendix B.

Mount accelerometer on each of the remaining *shear panels* at the center of the panel. Use tri-axial accelerometers on the ±Y sides to eliminate the need to re-instrument between tests. The accelerometer location information is listed in Appendix B.

Route the accelerometer cables through the second view port (not used for strain gage sensors) of the *shear plate*.

11.1.7 Test Fixture Final Assembly

Complete the test fixture assembly by replacing the two side *shear plates*. Be sure to put them on the ±Y sides to reduce set-up time for the thrust axis test. Engage the 3/8-16 x 1" fasteners (finger tight) to the *top plate* (P/N GLS-BTC5-5004) and the *base plate* (P/N GLS-BTC5-5002). Repeat for the opposite side. Ensure that all of the accelerometer cable and strain gage sensor cables have been properly connected and routed through the *shear plate* view ports before proceeding.

Replace the two *long shear plates* on the ±X sides. Engage the 3/8-16 x 1" fasteners (finger tight) to the *top plate* and the *base plate*. Repeat for the opposite side. Engage the ¼-20 x 1" fasteners (finger tight) to the *shear plates* on both sides of the *long shear plate*. Repeat for the opposite side. Torque the 3/8-16 screws to 20 ft-lbs and the ¼-20 screws to 64 in-lbs.

11.1.8 Test Fixture Instrumentation Set-Up

Secure five accelerometers to the test fixture +X side, one to the top plate (center), and two to the +Y side according to Appendix B. The +X side will be instrumented to measure the test fixture response as well as the input excitation during the transverse tests. The remaining accelerometers on the top and side plate will measure the response of the test fixture in the Y and Z directions.

The shaker table should be instrumented if necessary. The test fixture may be sufficient to accurately measure the input excitation from the test fixture base plate, however the thrust test may require one or more accelerometers to measure the input excitation. This should be decided by the test engineer performing the dynamic tests, and recorded in Appendix B.

Secure the accelerometer cables and strain gage sensor cables to the shaker table and connect them to the data acquisition system.

11.2 Transverse Axis Tests

The transverse axis testing will be conducted first. Perform the tests as outlined in this section according to the order they are listed. Record the run sequence, time of test, control channel, and data record file name on the table provided in Appendix A, Section 13.1. Be sure to record any stopped tests, reasons why, or changes to levels or sequence. This information will be critical when evaluating the test results. The following list is a test sequence guide and is not intended to be rigorously adhered to if changes to the order, levels, or type of test are necessary to achieve the goals of qualification testing.

1. Instrumentation Check 0.25 gpk at 20 Hz
2. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min
3. Sine Burst 2.5 gpk at 10 Hz : 5 cycles

4. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min
5. Random –6dB x 6.81 grms 20-2000 Hz : 30 sec
6. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min
7. Sine Burst 5 gpk at 10 Hz : 5 cycles
8. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min
9. Random 6.81 grms 20-2000 Hz : 60 sec : Limited
10. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min
11. Random 6.81 grms 20-2000 Hz : 60 sec : No Limit
12. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min
13. Random 6.81 grms 20-2000 Hz : 60 sec : No Limit (with PC Board included in calorimeter assembly)
14. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min

Evaluate the transfer functions after each test to ensure damage has not occurred during testing. Store the data records so they can be transported to HYTEC for processing.

11.3 Thrust Axis Tests

Perform the test set-up as outlined in sections 11.1.2 through 11.1.8 to mount the calorimeter to the vertical shaker.

The thrust axis test will be performed last because it is not considered to be as critical to the design qualification of the calorimeter. Perform the tests as outlined in this section according to the order they are listed. Record the run sequence, time of test, control channel, and data record file name on the table provided in Appendix A, Section 13.2. Be sure to record any stopped tests, reasons why, or changes to levels or sequence. This information will be critical when evaluating the test results. The following list is a test sequence guide and is not intended to be rigorously adhered to if changes to the order, levels, or type of test are necessary to achieve the goals of qualification testing.

15. Instrumentation Check 0.25 gpk at 20 Hz
16. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min
17. Sine Burst 4.125 gpk at 12.7 Hz : 5 cycles
18. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min
19. Random –6dB x 6.81 grms 20-2000 Hz : 30 sec
20. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min
21. Sine Burst 8.25 gpk at 12.7 Hz : 5 cycles
22. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min
23. Random 6.81 grms 20-2000 Hz : 60 sec : Limited
24. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min
25. Random 6.81 grms 20-2000 Hz : 60 sec : No Limit
26. Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min

Evaluate the transfer functions after each test to ensure damage has not occurred during testing. Store the data records so they can be transported to HYTEC for processing.

Disassemble the calorimeter and prepare it for transportation to a location that is to specified by NRL.

12. References

1. *General Environmental Specification for STS & ELV Payloads, Subsystems, and Components*, GEVS-SE Rev. A, System Reliability and Safety Office, Code 302, NASA/Goddard Space Flight Center, Greenbelt, MD, June 1996.
2. E. Ponslet, F. Biehl, W. O. Miller, and R. Smith, "Conceptual Mechanical Design of a CsI Calorimeter for GLAST," HYTEC Inc., HYTEC-TN-GLAST-03, June 1998.
3. F. Biehl, and E. Ponslet, "GLAST Calorimeter Static and Dynamic Structural Response to Launch Environment," HYTEC Inc., HYTEC-TN-GLAST-01, June 1998.
4. Shock and Vibration Handbook, 4th edition, C. M. Harris, editor, McGraw-Hill, 1996.
5. *GLAST Science Instruments – Spacecraft Interface Requirements Document*, August 3, 1999.
6. *NRL Naval Center for Space Technology, Process Specification, Installation of Bolts, Screws, Washers, Nuts and Hi-Lok Fasteners*, SSD-PS-018M Rev M, March 1, 1999.

13. *Appendix A:* Test Summary

The following table is to be used during testing to identify the order, times and type of test performed on the Shake Test 99 calorimeter.

13.1 Test Summary for the Transverse Axis

Shake Test 99 Calorimeter Test Summary – Transverse Axis					
Run	Time	Test Description	Axis	Control	File Name
		Transverse Shaker Operation Evaluation Test			
		Wedge Check 5 gpk at 20 Hz (0.25”pk-pk)	X		
		Random 6.81 grms 20-2000 Hz: 60 sec : Pre-Test	X		
		Sine Burst 5 gpk at 10 Hz : 5 cycles : Pre-Test	X		
		Calorimeter Test Parallel to the Transverse Axis			
		Instrumentation Check 0.25 gpk at 20 Hz	X		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min	X		
		Sine Burst 2.5 gpk at 10 Hz : 5 cycles	X		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min			
		Random –6dB x 6.81 grms 20-2000 Hz : 30 sec	X		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min	X		
		Sine Burst 5 gpk at 10 Hz : 5 cycles	X		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min	X		
		Random 6.81 grms 20-2000 Hz : 60 sec : Limited	X		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min	X		
		Random 6.81 grms 20-2000 Hz : 60 sec : No Limit	X		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min			

		Random 6.81 grms 20-2000 Hz : 60 sec : No Limit (with PC Board included in calorimeter assembly)	X		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min	X		

13.2 Test Summary for the Thrust Axis

Shake Test 99 Calorimeter Test Summary – Thrust Axis					
Run	Time	Test Description	Axis	Control	File Name
		Thrust Shaker Operation Evaluation Test			
		Wedge Check 5 gpk at 20 Hz (0.25"pk-pk)	Z		
		Random 6.81 grms 20-2000 Hz: 60 sec : Pre-Test	Z		
		Sine Burst 8.25 gpk at 12.7 Hz : 5 cycles : Pre-Test	Z		
		Calorimeter Test Parallel to the Thrust Axis			
		Instrumentation Check 0.25 gpk at 20 Hz	Z		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min	Z		
		Sine Burst 4.125 gpk at 12.7 Hz : 5 cycles	Z		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min	Z		
		Random –6dB x 6.81 grms 20-2000 Hz : 30 sec	Z		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min	Z		
		Sine Burst 8.25 gpk at 12.7 Hz : 5 cycles	Z		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min	Z		

		Random 6.81 grms 20-2000 Hz : 60 sec : Limited	Z		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min	Z		
		Random 6.81 grms 20-2000 Hz : 60 sec : No Limit	Z		
		Sine Sweep 0.5 gpk 10-2000 Hz : 4 Oct/min	Z		

14. *Appendix B:* Accelerometer Locations

The following are tables to record accelerometer locations for the random vibration tests performed on the Shake Test 99 Calorimeter.

14.1 Vibration Testing Parallel to the Transverse Axis

Accelerometer Information for the Transverse Axis Tests							
Location No.	**Cable No.**	**Channel No.**	**Type**	**Serial No.**	**Sensitivity (pC/g)**	**Test Axis**	**Location**
Shaker Table Instrumentation (Input Control Channel)							
1							Shaker Table Near Test Fixture
Calorimeter Instrumentation							
2							CsI Replacement Logs, +X Side, 1st Row Left
3							CsI Replacement Logs, +X Side, 1st Row Right
4							CsI Replacement Logs, +X Side, 2nd Row Left
5							CsI Replacement Logs, +X Side, 2nd Row Right
6							CsI Replacement Logs, +X Side, 3rd Row Left
7							CsI Replacement Logs, +X Side, 3rd Row Right
8							CsI Replacement Logs, +X Side, 4th Row Left
9							CsI Replacement Logs, +X Side, 4th Row Right
10							CsI Replacement Logs, +Y Side, 1st Row Left
11							CsI Replacement Logs, +Y Side, 1st Row Right
12							CsI Replacement Logs, +Y Side, 2nd Row Left
13							CsI Replacement Logs, +Y Side, 2nd Row Right
14							Top Compression Panel, +X edge, Center
15							Top Compression Panel, +Y edge, Center
16							Shear Panel, +X Side, Top-Center
17							Shear Panel, +X Side, Center-Center
18							Shear Panel, +X Side, Bottom-Center
19.1							Shear Panel, +Y Side, Center
19.2							Shear Panel, +Y Side, Center
19.3							Shear Panel, +Y Side, Center
20							Shear Panel, -X Side, Center

21.1							Shear Panel, -Y Side, Center
21.2							Shear Panel, -Y Side, Center
21.3							Shear Panel, -Y Side, Center
22							PC Board
23							PC Board
24							PC Board
Fixture Instrumentation							
25							Long Shear Plate, +X Side, Top Center
26							Long Shear Plate, +X Side, Center
27							Long Shear Plate, +X Side, Bottom Center
28							Shear Plate, +Y Side, Center
29							Top Plate, Center
30							Long Shear Plate, +X Side, Top Left
31							Long Shear Plate, +X Side, Top Right
32							Long Shear Plate, +X Side, Bottom Left
33							Long Shear Plate, +X Side, Bottom Right
34							Shear Plate, +Y Side, Top Left
35							Shear Plate, +Y Side, Top Center
36							Shear Plate, +Y Side, Top Right
37							Shear Plate, +Y Side, Bottom Left
38							Shear Plate, +Y Side, Bottom Center
39							Shear Plate, +Y Side, Bottom Right
Additional Instrumentation							
40							Containment Panel, +X Side, Left Center
41							Containment Panel, +X Side, Right Center
42							
43							

14.2 Vibration Testing Parallel to the Thrust Axis

Accelerometer Information for the Thrust Axis Tests							
Location No.	**Cable No.**	**Channel No.**	**Type**	**Serial No.**	**Sensitivity (pC/g)**	**Test Axis**	**Location**
Shaker Table Instrumentation (Input Control Channel)							
1							Shaker Table Near Test Fixture
Calorimeter Instrumentation							
2							CsI Replacement Logs, +X Side, 1st Row Left
3							CsI Replacement Logs, +X Side, 1st Row Right
4							CsI Replacement Logs, +X Side, 2nd Row Left
5							CsI Replacement Logs, +X Side, 2nd Row Right
6							CsI Replacement Logs, +X Side, 3rd Row Left
7							CsI Replacement Logs, +X Side, 3rd Row Right
8							CsI Replacement Logs, +X Side, 4th Row Left
9							CsI Replacement Logs, +X Side, 4th Row Right
10							CsI Replacement Logs, +Y Side, 1st Row Left
11							CsI Replacement Logs, +Y Side, 1st Row Right
12							CsI Replacement Logs, +Y Side, 2nd Row Left
13							CsI Replacement Logs, +Y Side, 2nd Row Right
14							Top Compression Panel, +X edge, Center
15							Top Compression Panel, +Y edge, Center
16							Shear Panel, +X Side, 1st Row Center
17							Shear Panel, +X Side, 2nd Row Center
18							Shear Panel, +X Side, 3rd Row Center
19.1							Shear Panel, +Y Side, Center
19.2							Shear Panel, +Y Side, Center
19.3							Shear Panel, +Y Side, Center
20							Shear Panel, -X Side, Center
21.1							Shear Panel, -Y Side, Center
21.2							Shear Panel, -Y Side, Center
21.3							Shear Panel, -Y Side, Center
22							None

23							None
24							None
Fixture Instrumentation							
25							Long Shear Plate, +X Side, Top Center
26							Long Shear Plate, +X Side, Center
27							Long Shear Plate, +X Side, Bottom Center
28							Shear Plate, +Y Side, Center
29							Top Plate, Center
30							Long Shear Plate, +X Side, Top Left
31							Long Shear Plate, +X Side, Top Right
32							Long Shear Plate, +X Side, Bottom Left
33							Long Shear Plate, +X Side, Bottom Right
34							Shear Plate, +Y Side, Top Left
35							Shear Plate, +Y Side, Top Center
36							Shear Plate, +Y Side, Top Right
37							Shear Plate, +Y Side, Bottom Left
38							Shear Plate, +Y Side, Bottom Center
39							Shear Plate, +Y Side, Bottom Right
Additional Instrumentation							
40							Containment Panel, +X Side, Left Center
41							Containment Panel, +X Side, Right Center
42							
43							

15. *Appendix C:* Strain Gage Sensor Locations

The following table identifies the strain gage sensor locations for those mounted on the Shake Test 99 calorimeter.

Strain Gage Sensor Locations for All Tests										
No.	**Type**	**Gage Factor**	**Location**	**Axis**	**Wire Pin-Out**				**Set-Up**	
					Block No.	Red	White	Black	Calibration Value	Signal Conditioner
E1	CEA-13-250UW-120	2.090 ±0.5%	Containment Panel, +X Side, Left Edge	Z						
E2	CEA-13-250UW-120	2.090 ±0.5%	Containment Panel, +X Side, Middle	Z						
E3	CEA-13-250UW-120	2.090 ±0.5%	Containment Panel, +X Side, Right Edge	Z						
F1	CEA-13-250UW-120	2.090 ±0.5%	Containment Panel, +Y Side, Left Edge	Z						
F2	CEA-13-250UW-120	2.090 ±0.5%	Containment Panel, +Y Side, Middle	Z						
F3	CEA-13-250UW-120	2.090 ±0.5%	Containment Panel, +Y Side, Right Edge	Z						
G1	CEA-13-250UW-120	2.090 ±0.5%	Containment Panel, -X Side, Left Edge	Z						
G2	CEA-13-250UW-120	2.090 ±0.5%	Containment Panel, -X Side, Middle	Z						
G3	CEA-13-250UW-120	2.090 ±0.5%	Containment Panel, -X Side, Right Edge	Z						
H1	CEA-13-250UW-120	2.090 ±0.5%	Containment Panel, -Y Side, Left Edge	Z						
H2	CEA-13-250UW-120	2.090 ±0.5%	Containment Panel, -Y Side, Middle	Z						
H3	CEA-13-250UW-120	2.090 ±0.5%	Containment Panel, -Y Side, Right Edge	Z						
L1	CEA-13-250UW-120	2.090 ±0.5%	Top Compression Panel, Middle	X						
L2	CEA-13-250UW-120	2.090 ±0.5%	Top Compression Panel, Middle	Y						
K1	CEA-13-250UW-120	2.090	Bottom Compression	X						

		±0.5%	Panel, Middle							
K2	CEA-13-250UW-120	2.090 ±0.5%	Bottom Compression Panel, Middle	Y						
•	CEA-13-125UR-120 (Rosette)	2.110 ±0.5%	Shear Panel, +X Side, Middle	-45°						
•		2.145 ±0.5%		Z						
•		2.110 ±0.5%		+45°						
M1	CEA-13-125UR-120 (Rosette)	2.110 ±0.5%	Shear Panel, +Y Side, Middle	-45°						
M2		2.145 ±0.5%		Z						
M3		2.110 ±0.5%		+45°						
•	CEA-13-125UR-120 (Rosette)	2.110 ±0.5%	Shear Panel, -X Side, Middle	-45°						
•		2.145 ±0.5%		Z						
•		2.110 ±0.5%		+45°						
N1	CEA-13-125UR-120 (Rosette)	2.110 ±0.5%	Shear Panel, -Y Side, Middle	-45°						
N2		2.145 ±0.5%		Z						
N3		2.110 ±0.5%		+45°						

16. *Appendix D:* Shake Test 99 Calorimeter Mechanical Drawings

17. *Appendix E:* Mechanical Drawings of the Vibration Test Fixture